Passive Acoustic Monitoring of Large Whales in Offshore Waters of British Columbia

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PASSIVE ACOUSTIC MONITORING OF LARGE WHALES IN OFFSHORE WATERS OF BRITISH COLUMBIA

by

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TABLE OF CONTENTS

ABSTRACT

Ford, J.K.B., Koot, B., Vagle, S., Hall-Patch, N., and Kamitakahara, G. 2010. Passive acoustic monitoring of large whales in offshore waters of British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2898 v + 30 p.

Two deployments of a submersible, autonomous recording instrument were undertaken off the west coast of Vancouver Island, British Columbia, to assess patterns of cetacean occurrence. One deployment was at Union Seamount in 2006, and the other at La Perouse Bank in 2007. The instrument recorded sound between 5 and 1000 Hz, a frequency range that is sufficient to record the vocalizations of the large whale species known to occur in British Columbia waters, including humpback, fin, sei, grey, blue, minke and North Pacific right whales (baleen whales), and the sperm whale (a toothed whale). Humpback, fin and sperm whales were detected frequently at both Union Seamount and La Perouse Bank, and showed some seasonality in occurrence. A small number of vocalizations that may have been produced by sei whales were detected at each site, and blue whale vocalizations were detected at La Perouse Bank on three days in September. No right whale vocalizations were detected at either site. Year-round acoustic monitoring has the potential to yield important data on the seasonal occurrence of cetaceans off the British Columbia coast. Such information would be a valuable supplement to on-going shipboard survey efforts, especially for cetaceans listed as endangered and threatened under the Species at Risk Act.

RÉSUMÉ

Ford, J.K.B., Koot, B., Vagle, S., Hall-Patch, N., and Kamitakahara, G. 2010. Passive acoustic monitoring of large whales in offshore waters of British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2898 v + 30 p.

Deux déploiements d'un appareil d'enregistrement submersible autonome ont été effectués au large de la côte ouest de l'île de Vancouver, en Colombie-Britannique, en vue d'étudier les profils d'occurrence de cétacés. L'un des déploiements a eu lieu sur le mont sous-marin Union, en 2006, et l'autre, sur le banc La Pérouse, en 2007. Le submersible a enregistré des sons de 5 à 1 000 Hz, une fourchette de fréquences suffisante pour enregistrer les vocalisations d'espèces de baleines de grande taille qui fréquentent les eaux de la Colombie-Britannique, notamment de rorquals à bosse, de rorquals communs, de rorquals boréaux, de baleines grises, de rorquals bleus, de petits rorquals, de baleines noires du Pacifique Nord (cétacés à fanons) et de cachalots macrocéphales (cétacé à dents). Des rorquals à bosse, des rorquals communs et des cachalots macrocéphales ont été fréquemment détectés sur le mont Union et sur le banc La Pérouse, et leur profil d'occurrence montrait des fluctuations saisonnières. Un petit nombre de vocalisations, probablement de rorquals boréaux, ont été détectées dans chaque site, et des vocalisations de rorquals bleus ont été détectées sur le banc La Pérouse trois jours en septembre. Aucune vocalisation de baleine noire n'a été détectée. La surveillance acoustique tout au long de l'année permettrait probablement de recueillir des données importantes sur l'occurrence saisonnière des cétacés au large de la côte de la Colombie-Britannique. De telles données seraient très utiles pour compléter les données recueillies lors de relevés continus à bord de navires, particulièrement en ce qui concerne les espèces de cétacés désignées « en voie de disparition » et « menacées » aux termes de la *Loi sur les espèces en péril*.

1.0 INTRODUCTION

Passive acoustic methods are becoming increasingly widespread in field studies to assess cetacean populations. They can be a valuable supplement to traditional visual cetacean survey methods, particularly for rare cetaceans (Mellinger et al. 2007). In joint visual-acoustic surveys, acoustic monitoring has been shown to detect up to ten times more cetacean groups than visual methods (Mellinger et al. 2007). Fixed passive acoustic recording is a useful tool for monitoring cetaceans because it provides long time-series of data at a relatively low cost, and cetaceans can be accurately detected in any type of weather or sea-state, and at any time of day or year. Passive acoustic monitoring is particularly effective for detecting rare species that would have a very low probability of being detected by visual methods.

Many large whale species that inhabit or migrate through offshore waters of British Columbia use acoustic signals for communication or echolocation, and so can be monitored using passive acoustic methods. Vocalizations can provide information on the presence of a species (e.g., detection of the rare North Pacific right whale *Eubalaena japonica* in the Gulf of Alaska, Mellinger et al. 2004); seasonality (e.g., singing of humpback whales (*Megaptera novaeangliae*), Norris et al. 1999); population density (e.g., fin whales (*Balaenoptera physalus*), McDonald and Fox 1999); and population identity (e.g. northeastern and northwestern Pacific blue whales (*Balaenoptera musculus*), Stafford et al. 2001).

Blue, fin, sei, humpback, and right whales off the Pacific coast of Canada are legally listed under the Species at Risk Act (SARA). Recovery strategies and action plans have highlighted the need for better knowledge of occurrence, distribution, abundance and habitats of these species in Pacific Canadian waters, and passive acoustic monitoring has been identified as a key component in collecting this type of information (Gregr et al. 2006; Fisheries and Oceans Canada 2010a, 2010b, 2010c). In this report we describe cetacean vocalizations detected from two deployments of an acoustic recording instrument off the British Columbia coast during 2006-07. These represent the first stages of a long-term project for multi-species remote acoustic monitoring in the region. These instruments recorded ambient sound at frequencies of 5-1000 Hz, a range that allows detection of the vocalizations of the baleen whales (humpback, fin, blue, grey (*Eschrichtius robustus*), common minke (*Balaenoptera acutorostrata)*, sei (*Balaenoptera borealis*), and North Pacific right whale) and of the sperm whale *(Physeter macrocephalus*).

2.0 METHODS

2.1 STUDY AREA

A custom-designed acoustic recording instrument (Vagle et al. 2004) was deployed in two locations off the coast of British Columbia, representing two different types of marine habitat (Table 1, Figure 1). The instrument was first deployed at Union

Seamount, representing offshore pelagic habitat, and then re-deployed at La Perouse Bank, representing productive shelf-break habitat. Union Seamount is located approximately 420 km west of Nootka Sound, Vancouver Island, and rises to 293 meters below the sea surface. La Perouse Bank is situated approximately 50 km southwest of Barkley Sound, Vancouver Island, in a productive coastal upwelling system (Robinson and Ware 1999). It is a shallow bank (50-150 m) on a section of continental shelf that has particularly convoluted bathymetry, consisting of series of deep basins separated by shallow banks (Foreman and Thomson 1997).

Table 1. Details of PATC deployments.

Location	Deployment period	Water Depth (m)	Hydrophone Depth (m)
Union Seamount (49°34.03' N, 132°47.0' W)	9 February to 18 July, 2006	500	50
La Perouse Bank (48°32.070' N, 126°12.402' W)	20 May to 16 September, 2007	500	50

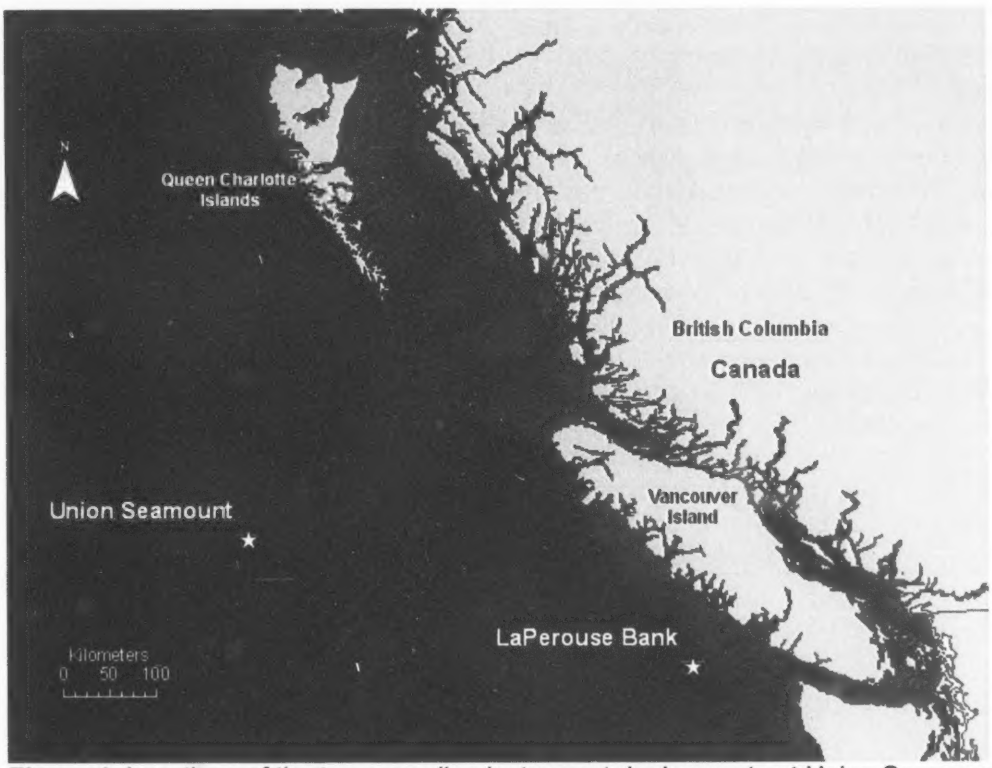

Figure 1. Locations of the two recording instrument deployments at Union Seamount and La Perouse Bank, off the west coast of Vancouver Island, British Columbia, Canada.

2.2 DATA COLLECTION

The PATC (Passive Acoustic Tracking of Cetaceans) recording instrument was developed by the Instrument Development Group (IDG/OS), at the Institute of Ocean Sciences (IOS). The PATC instrument consisted of a broadband hydrophone, pre-amplifier with an automatic gain control circuit, an analog acoustic pattern recognition circuit, two low-pass filters (900 Hz and 10 kHz), an analog to digital converter, a CFI micro controller, and hard drives for data storage (Figure 2, Vagle et al. 2004). The instrument was encased in an aluminum pressure housing and suspended above the sea floor using a mooring made up of anchors and floats. An acoustic release mechanism was incorporated for retrieval of the instrument. All hardware linkages on the moorings were "quietened" with the insertion of rubber isolators and PVC tape.

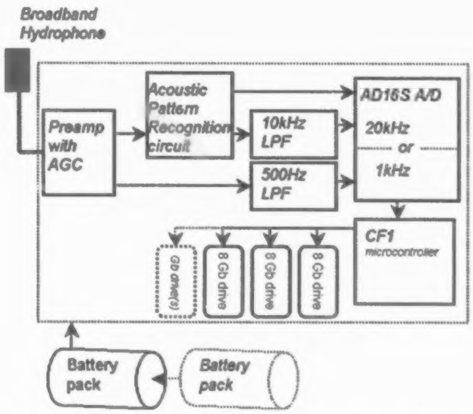

Figure 2. Schematic diagram showing the main components of the self-contained PATC instrument designed for offshore large baleen and killer whale monitoring (From Vagle et al. 2004).

The PATC recording instrument was designed to be a dual bandwidth system, recording either at low frequencies for the detection of large whales or at higher frequencies to record killer whales and other high frequency cetaceans. To accomplish this, the instrument was programmed to record on a timed 1-hr on / 1-hr off duty cycle at a limited 5-1000 Hz bandwidth or at a wider 5-10500 Hz bandwidth for 10 min when higher frequency signals were detected by an acoustic pattern recognition algorithm that was incorporated into the instrument's operating software. The system was allocated a fixed number of these higher frequency recording periods per day and if the quota was used up on a given day the system did not record any more that day. However, if the quota from one day was not used, this number of recording periods was added to the quota for the next day to allow for more frequent sampling during some limited periods when killer whales or other high frequency signals were detected. If no killer whales were detected over a predetermined period (typically one week) the system recorded ambient noise to fill up part of the quota (Vagle et al. 2004).

2.3 ACOUSTIC ANALYSIS

This report focuses on the lower frequency recording samples from the PATC deployments – analyses of the higher frequency recordings are not included here. However, due to the recording schedule (described above), the one-hour long low frequency recordings were often interrupted when the system switched to higher frequency recording. Therefore, the higher frequency recordings were re-sampled to the same sample rate (1954 Hz) as the lower frequency recordings and then analyzed, in order to fill in the gaps in the low frequency recordings.

Recordings (.wav files) were visually inspected as spectrograms using Adobe® Audition™ 1.5 software. If a call was observed visually, the recording was examined aurally and species was inferred when possible. In this way, every hour-long recording segment was examined for large whale vocalizations, and when a species was detected, it was scored as present in that hour irrespective of the number of vocalizations detected in that hour. Vocalizations from multiple individuals of the same species were not accounted for. For each species, number of detections were expressed as a proportion of the total number of one-hour long recording segments per day (i.e., if a humpback whale was detected in 9 hour-long segments out of a total of 12 hour-long segments in one day, the proportion for that day was 9/12= 0.75). Spectrograms of good quality samples of signals from each species identified at each site were made using the program Amadeus Pro, Version 1.5 (HairerSoft, Kenilworth, UK).

3.0 RESULTS AND DISCUSSION

The vocalizations of humpback, sperm, and fin whales were detected at both Union Seamount and La Perouse Bank locations (Table 2, Figures 3 and 4). Humpback whale vocalizations were the most frequently detected signals at both locations. At each site, a few vocalizations that were possibly produced by sei whales were detected. Blue whale vocalizations were detected in a small number of recordings at La Perouse Bank, but not at Union Seamount (Table 2, Figure 4).

Table 2. Results from analysis of recordings from Union Seamount and La Perouse Bank deployments. Total number of hour-long recording segments and number of consecutive days of recording at each site are given, as well as the number of detections of each species expressed as the total number hour-long segments containing that species' calls, and as a proportion of the total number of hour-long segments collected at each site.

Location	Total 1-hour recording segments (# days of recording)	Hours containing calls (# of hour-long segments/proportion of total hours)				
		Humpback	Sperm	Fin	Possible sei	Blue
Union Seamount	1915 hours (160 days)	299/0.16	52/0.03	89/0.05	19/0.01	0/0
La Perouse Bank	1449 hours (121 days)	292/0.20	214/0.15	123/0.09	12/0.01	7/0.005

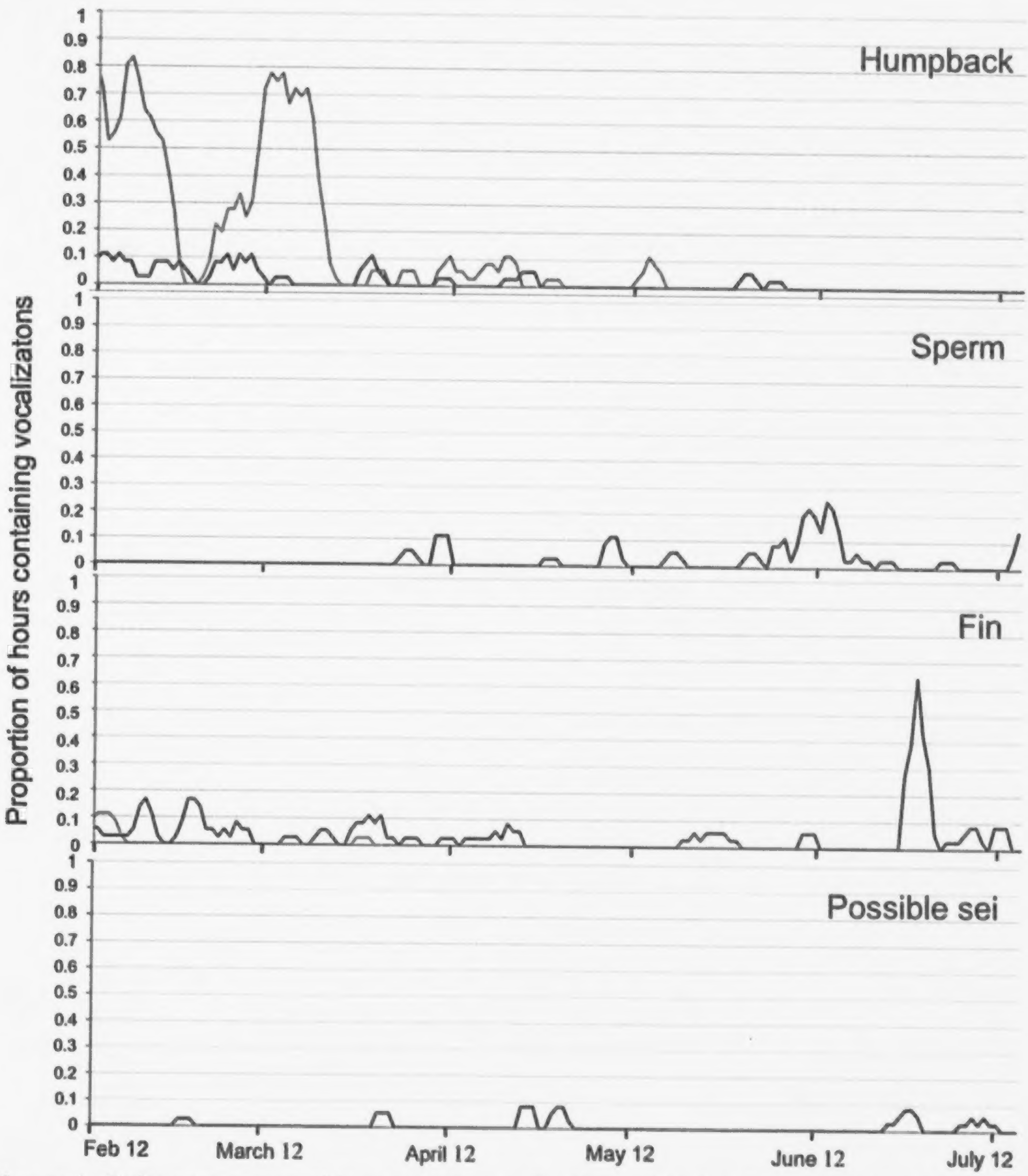

Figure 3. Daily occurrence of large whale vocalizations at Union Seamount in 2006, plotted as the proportion of one-hour segments that contain vocalizations, using a 3-day moving average. For humpback whale, grey line represents proportion of song type vocalizations and black line represents social type vocalizations (see Section 3.1). For fin whale, grey line represents proportion of stereotyped 20 Hz calls and black line represents proportion of irregular-interval type vocalizations (see Section 3.3). Proportions are calculated as the number of one-hour segments per day containing vocalizations divided by the total number of one-hour segments per day (which was always 12 except for 5 days that had 11 hour-long segments).

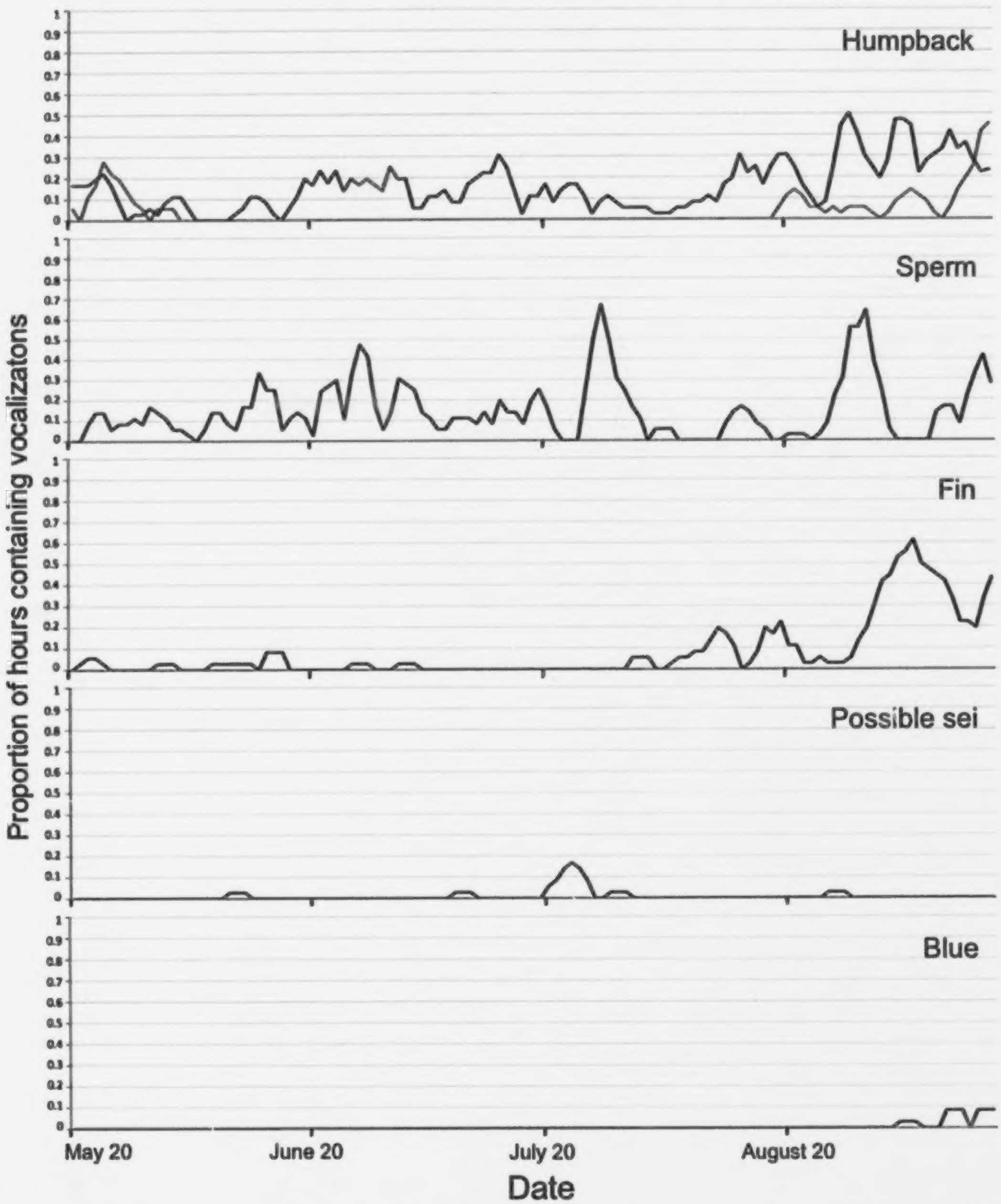

Figure 4. Daily occurrence of large whale vocalizations at La Perouse Bank in 2007, plotted as the proportion of one-hour segments that contain vocalizations, using a 3-day moving average. For humpback whale, grey line represents proportion of song type vocalizations and black line represents social type vocalizations (see Section 3.1). For fin whale, black line represents proportion of irregular interval type vocalizations (see Section 3.3). Proportions are calculated as the number of one-hour segments per day containing vocalizations divided by the total number of one-hour segments per day (which was always 12 except for 3 days that had 11 hour-long segments).

It is important to note that whales may be present and not vocalizing, so a lack of calls does not necessarily indicate that no whales were present. Although amount of vocal activity can give a rough indication of numbers of whales within acoustic range of the recording instrument, no attempt was made to infer number of vocalizing individuals from this dataset.

3.1 HUMPBACK WHALE

Male humpback whales produce complex, structured, series of vocalizations called song, primarily on their low latitude winter breeding grounds (see Appendix, Payne and McVay 1971). The basic sound units within songs last from 0.1 to 10 seconds, with most energy between 200-2500 Hz (Payne and Payne 1985). Sound units are grouped into phrases, and phrases are grouped into themes, which in turn are organized into a pattern that repeats in a fairly rigid order to make up a song (Payne et al. 1983).

Humpback whales also produce social sounds (see Appendix). Social sounds are any sound that is not part of a song, and include sounds generated during feeding (Cerchio and Dahlheim 2001), migration (Dunlop et al. 2008), and interactions in competitive groups on breeding grounds (Silber 1986). Units within a song may be used as social sounds, the difference being that song is a long, continuous, patterned, complex signal, whereas social sounds are un-patterned and occur in short bursts (Dunlop et al. 2008). Social sounds are produced by both sexes (Dunlop et al. 2008). Humpback whale vocalizations detected at Union Seamount and La Perouse Bank included both song (Figures 5 and 6) and social sounds (Figures 7 and 8).

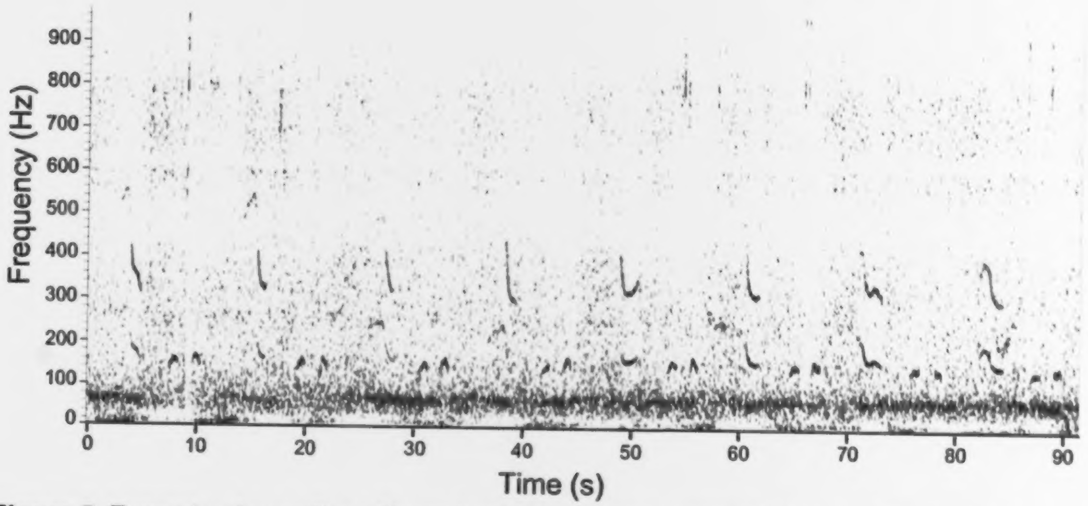

Figure 5. Example of a section of humpback whale song recorded at Union Seamount; spectrogram parameters: 512 pixels image height, 977 Hz max frequency, 512 FFT size, Hanning window.

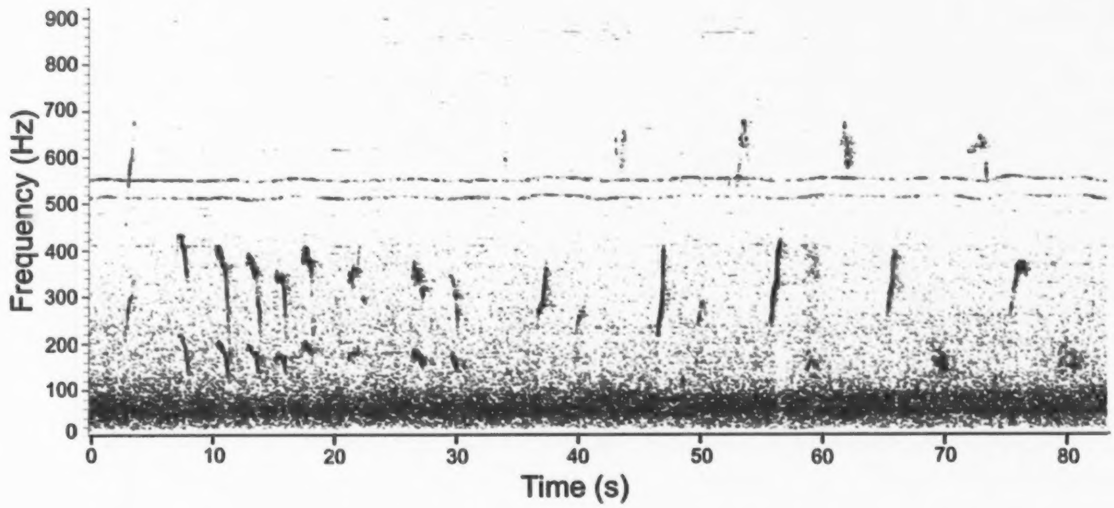

Figure 6. Example of a section of humpback whale song recorded at La Perouse Bank. Spectrogram parameters: 512 pixels image height, 977 Hz max frequency, 1024 FFT size, Hanning window.

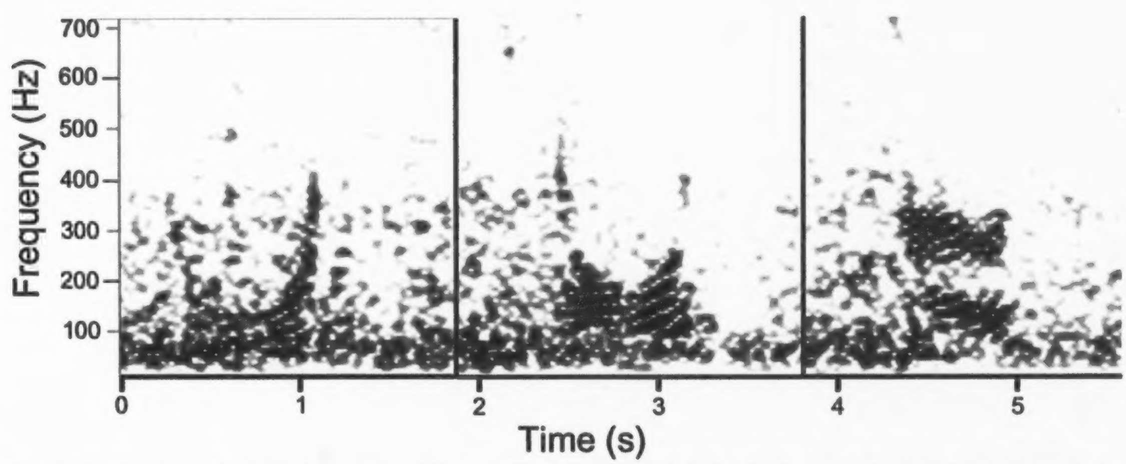

Figure 7. Composite spectrogram of three different humpback whale social sounds recorded at Union Seamount. Spectrogram parameters: 256 pixels image height, 977 Hz max frequency, 256 FFT size, Hanning window.

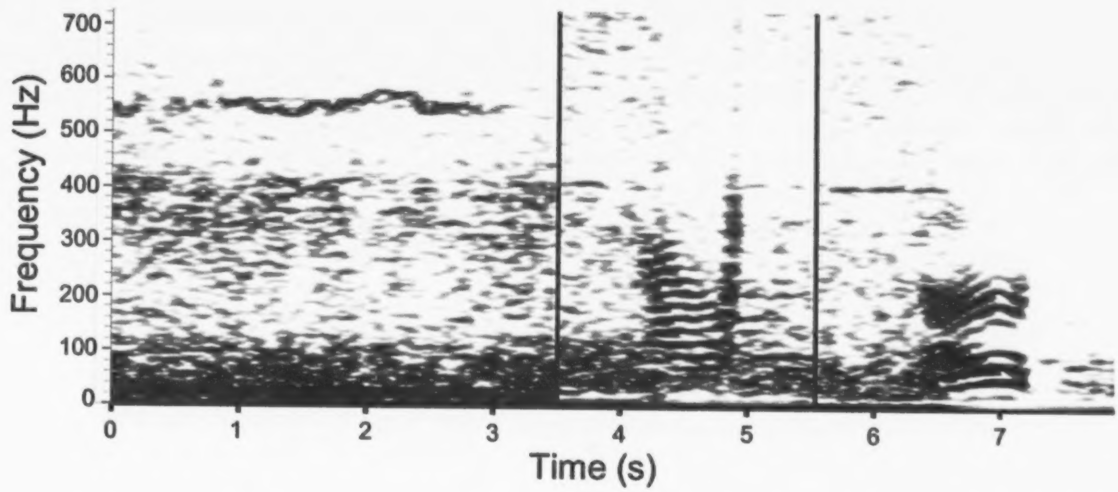

Figure 8. Composite spectrogram of three different humpback whale social sounds recorded at La Perouse Bank. Spectrogram parameters: 512 pixels image height, 977 Hz max frequency, 512 FFT size, Hanning window.

Humpback whale song has been documented at higher latitudes during northbound migrations in the spring (Norris et al. 1999) and on summer feeding grounds (Gabriele and Frankel 2002, Clark and Clapham 2004). At Union Seamount, humpback whale song was detected frequently in winter and early spring (February and March), with lower levels of singing continuing until mid May, and no singing occurring throughout the rest of spring and early summer months until the end of the study period (July 18) (Figure 3). This winter and spring occurrence of song suggests that Union Seamount may be on a northward migration path. At La Perouse Bank, humpback whale song was also detected in the spring, though at lower levels and later in the season than at Union Seamount (Figure 4). Singing ceased just before the end of spring and started again towards the end of summer. The singing in late spring at La Perouse Bank may represent whales arriving at summer feeding grounds, and the singing in late summer may be due to changes in the males as breeding season nears (possibly due to an increase in testosterone levels, Clark and Clapham 2004).

Humpback whale social sounds were detected at low levels in the winter and early spring at Union Seamount with almost no detections after April (Figure 3). Social sounds were detected more frequently and throughout the study period at La Perouse Bank (Figure 4). This pattern may help support the hypothesis that Union Seamount is on a migration path, with whales only passing through during winter and spring, and that La Perouse Bank is a feeding ground, with whales present throughout the summer.

3.2 SPERM WHALE

Sperm whales produce sharp, broadband, impulsive clicks (Bachus and Schevill 1966). So-called "usual clicks" (See Appendix, Weilgart and Whitehead 1988) are used in echolocation to detect prey (Gordon 1987), and stereotyped patterns of clicks, called

codas, are believed to be a form of communication used to maintain social structure in female groups (Watkins and Schevill 1977, Marcoux et al. 2006). Females and young tend to stay in tropical and subtropical waters between the 40° N and S latitude parallels. In the eastern North Pacific, the females' range extends as far north as Vancouver Island (Reeves and Whitehead 1997), where they are found in smaller numbers and less predictable locations than the males (Gregr and Trites 2001). Males separate from the female groups and move north in the summer to feed in the Gulf of Alaska, Bering Sea and Aleutian Islands, and to move back within the 40° latitude parallels in the winter (Rice 1989, Angliss and Lodge 2003).

Usual clicks produced by sperm whales were detected at both Union Seamount and La Perouse Bank (Figures 9 and 10).

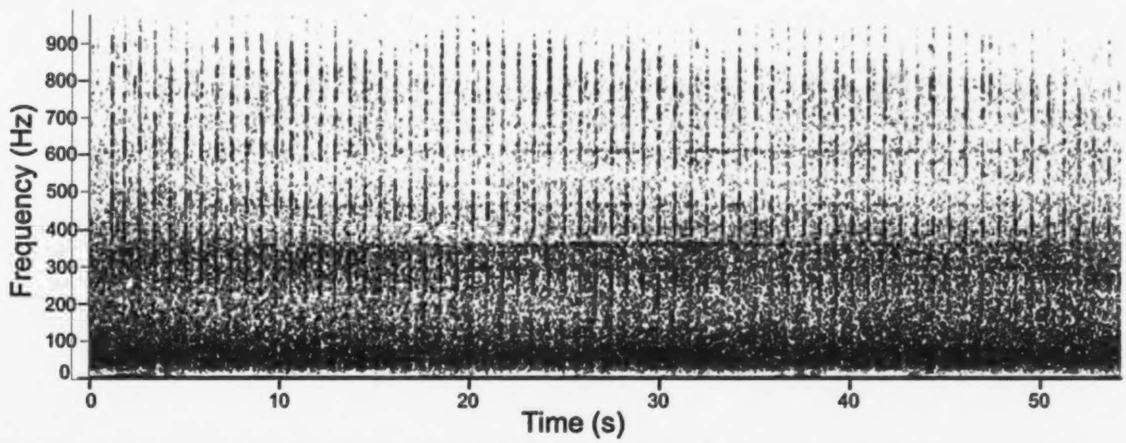

Figure 9. Example of sperm whale clicks at Union Seamount. Spectrogram parameters: 256 pixels image height, 977 Hz max frequency, 512 FFT size, Hanning window.

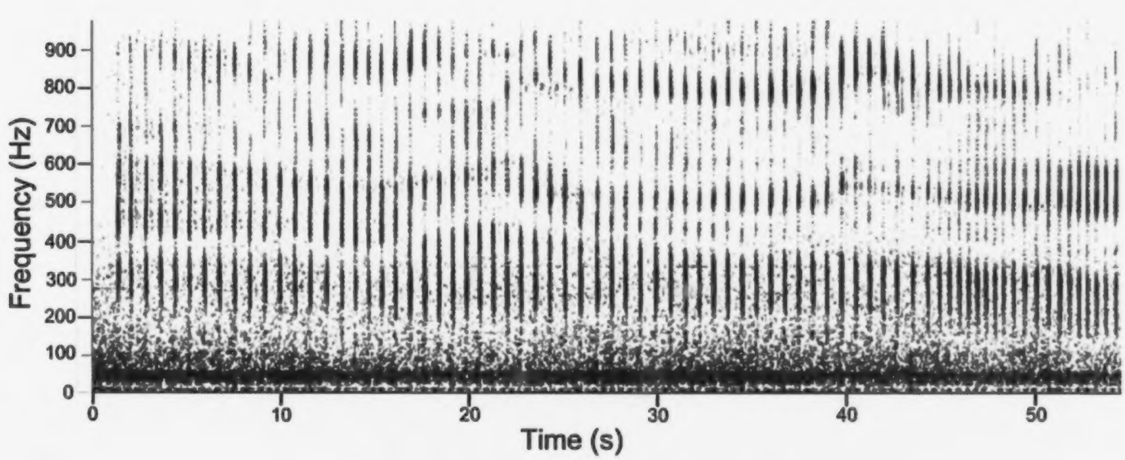

Figure 10. Example of sperm whale clicks at La Perouse Bank. Spectrogram parameters: 256 pixels image height, 977 Hz max frequency, 512 FFT size, Hanning window.

At Union Seamount, sperm whale clicks were first detected in April and continued until the end of the study period in mid July (Figure 3). Sperm whale clicks were recorded throughout the study period (mid May to mid September) at La Perouse Bank (Figure 4). These detections of sperm whales in BC waters in the summer coincide with the period that male sperm whales move north of 40° N latitude in the summer (Angliss and Lodge 2003, Gregr and Trites 2001), but could also be partially explained by the potential presence of female groups (Reeves and Whitehead 1997). However, there were no detections of codas at either site.

Sperm whale clicks occurred at a higher rate at La Perouse Bank than at Union Seamount (Table 2, Figures 3 and 4). Sperm whales are found in waters with higher chlorophyll concentration than adjacent waters, such as areas of upwelling (Jaquet et al. 1996), and are closely associated with the shelf break in BC waters (Gregr and Trites 2001). The higher rate of sperm whale detections at La Perouse Bank would be expected as it is situated in a productive upwelling zone on the shelf break, in contrast to Union Seamount which is in a less productive, pelagic setting far from the shelf break (Figure 1).

3.3 FIN WHALE

Fin whales produce stereotyped pulses and "irregular repetition interval" call types (see Appendix, McDonald and Fox 1999). The stereotyped pulse contains most energy around 20 Hz, has a downward sweep in frequency of about 6 Hz (Watkins et al. 1987, Thompson et al. 1992), and little or no harmonic energy. The pulse is about 0.8 s long, and can be repeated for hours or days at regular intervals of about 6 to 46 s (Watkins et al. 1987). It is believed that the 20 Hz pulse is a male breeding call (Watkins et al. 1987) but irregular repetition interval call types are used in other behavioral contexts (McDonald and Fox 1999). A call type with 20-35 Hz downswept pulses at irregular repetition intervals makes up 90% of fin whale calls in higher North Pacific latitudes during the summer (McDonald and Fox 1999). Another call type with 30 to 90 Hz downswept pulses at shorter and more irregular repetition intervals represents only a small fraction of calls at any latitude (McDonald and Fox 1999).

The stereotyped 20 Hz pulse call type (Figure 11) was detected a small number of times at Union Seamount, and not at all at La Perouse Bank. Irregular repetition interval call types were detected at Union Seamount and La Perouse Bank (Figures 12 and 13).

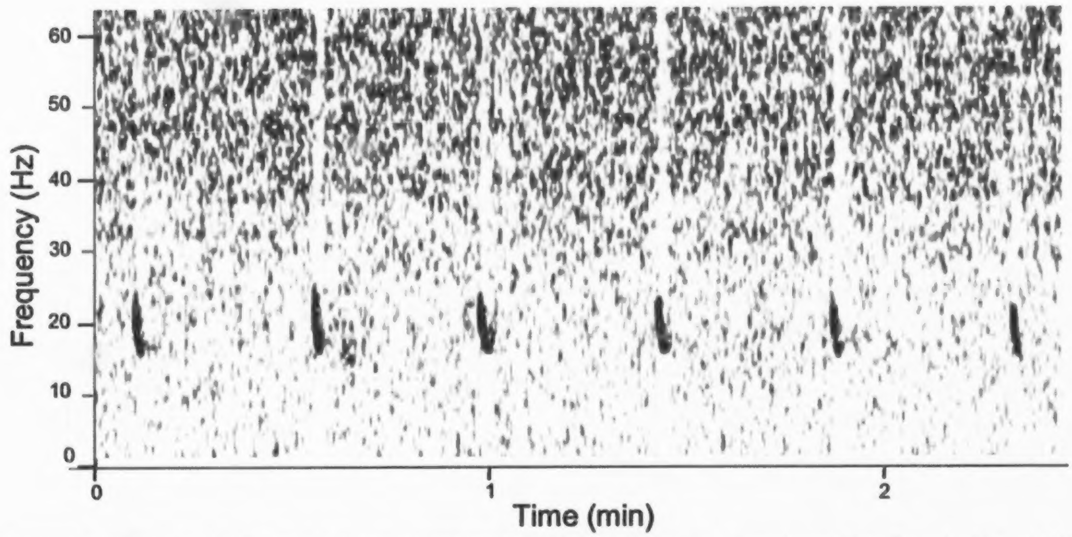

Figure 11. Example from a series of stereotyped 20 Hz pulses produced by fin whales at Union Seamount. Spectrogram parameters: 512 pixels image height, 162.83 Hz max frequency, 512 FFT size, Hanning window.

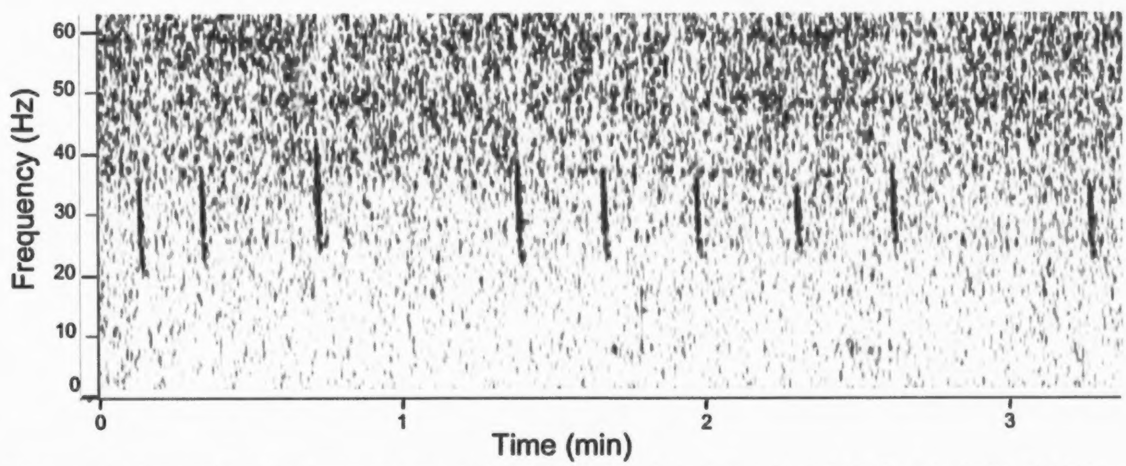

Figure 12. Example of an irregular repetition interval call type produced by fin whale(s) at Union Seamount. Spectrogram parameters: 512 pixels image height, 162.83 Hz max frequency, 512 FFT size, Hanning window.

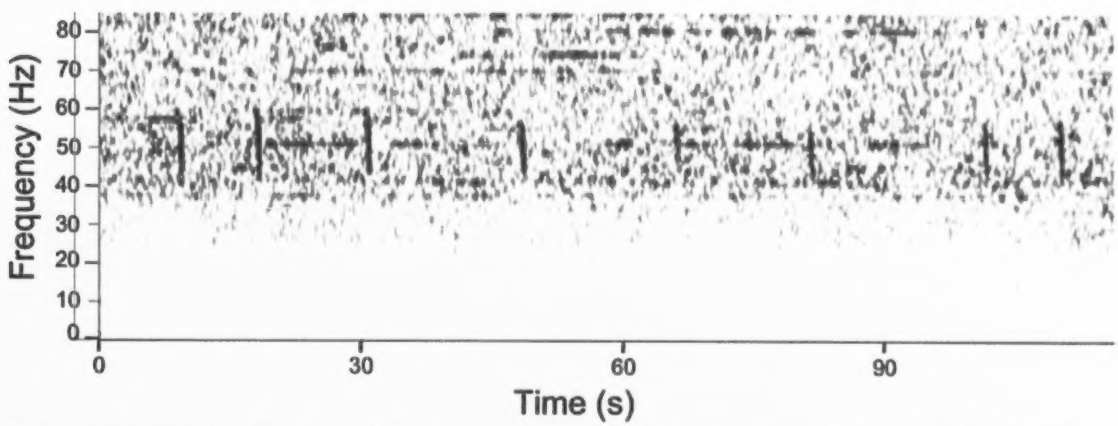

Figure 13. Example of an irregular repetition interval call type produced by fin whale(s) at La Perouse Bank. Spectrogram parameters: 512 pixels image height, 244.25 Hz max frequency, 512 FFT size, Hanning window.

Fin whale irregular repetition interval calls were detected at a fairly consistent but low rate at both sites, with the exception of a noticeable increase at the end of August and beginning of September at La Perouse Bank (Figures 3 and 4). The stereotyped 20 Hz pulse call type was detected only a few times at Union Seamount in February and early April (Figure 4). In the eastern North Pacific, production of the stereotyped 20 Hz pulse by fin whales is seasonal, with most calling occurring between October and April, coinciding with the winter breeding period, and little calling during the summer months (Watkins et al. 1987, Watkins et al. 2000).

3.4 SEI WHALE

Sei whale vocalization is poorly documented, with only five published descriptions of their calls (Table 3, Baumgartner et al. 2008). Sei whale vocalization has been reported in the North Atlantic (Thompson et al. 1979, Knowlton et al. 1991, Baumgartner 2008), the Southern Ocean near the Antarctic Peninsula (McDonald et al. 2005), and off the Hawaiian Islands (Rankin and Barlow 2007). Rankin and Barlow (2007) reported that sounds they recorded from sei whales (see Appendix) were similar to sounds that are produced by most balaenopterids, particularly fin whales. Sei whale vocalizations closely resemble the 20 to 35 Hz irregular repetition interval downswept pulses produced by fin whales (Rankin and Barlow 2007). These fin whale calls could easily be confused with sei whale vocalizations as both are pulsive and downswept and there is considerable overlap in their frequency structure. The sei whale vocalization is different than the fin whale vocalization only in that it is slightly longer in duration (1.2 s compared to a typical fin whale call of 0.8 s), and this slight difference is not enough to unambiguously distinguish between vocalizations of the two species (Rankin and Barlow 2007).

Table 3. Summary of structural characteristics of sei whale vocalizations. Source of the information, location, time of year and characteristics of calls are provided.

Source	Location	Time of year	Sample size	Shape	Average duration (s)	Average max (Hz)	Average min (Hz)
Thompson et al. 1979	North Atlantic	Summer		2-part pulse	0.7	3500	1500
Knowlton et al. 1991	North Atlantic	Summer		Sweeps	1.4 to 2.6	3500	1500
McDonald et al. 2005	Southern Ocean	Summer	18	Tonal and swept, and broadband	1.1 (+/- 0.6) (swept)	700	200
Rankin and Barlow 2007; *High frequency sweep*	North Pacific	Late fall	2	Downsweep	1.2 (SD=0.07)	100.3 (SD=11.1)	44.6 (SD=2.9)
Rankin and Barlow 2007; *Low frequency sweep*	North Pacific	Late fall	105	Downsweep	1.2 (SD=0.11)	39.4 (SD=3.4)	21.0 (SD=2.4)
Baumgartner et al. 2008	North Atlantic	Spring	108	Downsweep	1.38 (SD=0.37)	82.3 (SD=15.2)	34.0 (SD=6.2)

At both Union Seamount and La Perouse Bank, vocalizations that could possibly be attributed to sei whales were detected on several occasions (Figures 14, 15 and 16). At Union Seamount, the calls (n=18) had a mean duration of 1.31 s (SD=0.72 s) and swept downwards from 96.57 Hz (SD=61.05 Hz) to 39.33 Hz (SD=7.04 Hz). At La Perouse Bank, the calls (n=11) had a mean duration of 1.60 s (SD=0.89 s) and swept downwards from 76.36 Hz (SD=17.62 Hz) to 41.45 Hz (SD=8.90 Hz). These values closely resemble measurements made from sei whale calls recorded in the North Pacific by Rankin and Barlow (2007) and in the Atlantic by Baumgartner et al. (2008) (Table 3). However, due to their similarity to fin whale calls it cannot be concluded that these signals were actually produced by sei whales.

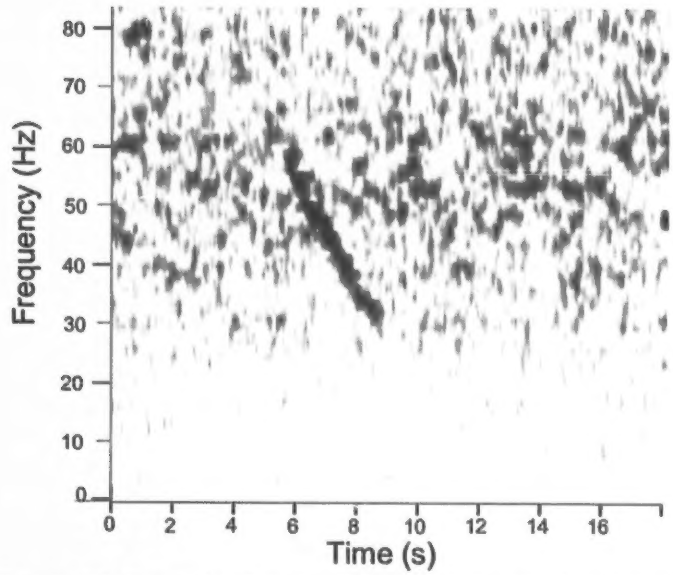

Figure 14. Example of a possible sei whale vocalization at Union Seamount, 1 April 2006. Spectrogram parameters: 512 pixels image height, 162.83 Hz max frequency, 256 FFT size, Hanning window.

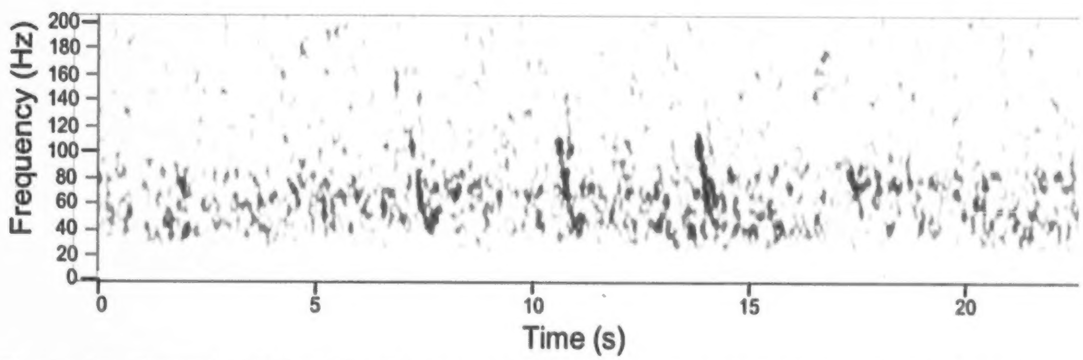

Figure 15. Example of a series of three possible sei whale vocalizations at Union Seamount, 7 July 2006. Spectrogram parameters: 512 pixels image height, 977 Hz max frequency, 512 FFT size, Hanning window.

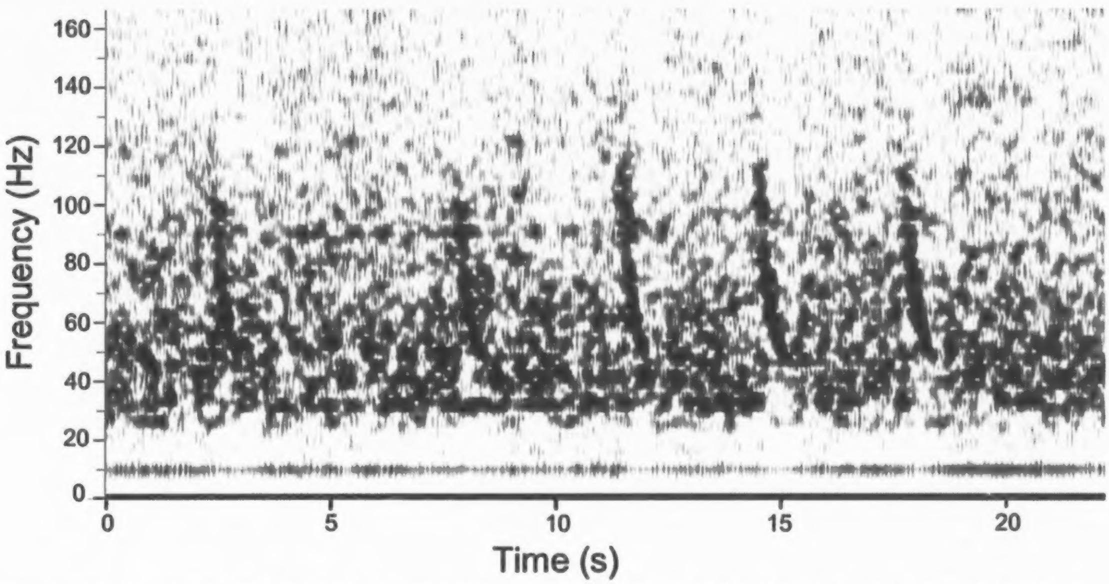

Figure 16. Example of a series of five possible sei whale vocalizations at La Perouse Bank, 8 August 2007. Spectrogram parameters: 512 pixels image height, 244.25 Hz max frequency, 256 FFT size, Hanning window.

These possible sei whale calls were detected a small number of times throughout the study periods at both Union Seamount and La Perouse Bank (Figures 3 and 4).

3.5 BLUE WHALE

Blue whales in the North Pacific produce two distinct vocalization types representing two different populations, a northwestern and a northeastern population (see Appendix, Stafford et al. 2001, McDonald et al. 2006). The northeastern Pacific vocalization type consists predominantly of a repeating pattern of two calls. The first call, termed the "A" call, is amplitude modulated, and the second call, termed the "B" call, is a frequency modulated downsweep (Stafford et al. 2001). On average, the A call is 18.2 s long with a fundamental frequency of 15.3 Hz. The B call is 17.5 s long and consists of harmonically related tones, with the fundamental frequency sweeping from 18 Hz to to 16.1 Hz, and a prominent third harmonic at around 48 Hz. The average time between A and B calls is 25.6 s (Stafford et al. 2001). Sometimes a third sound (termed C) occurs between part A and B at 11 Hz (Stafford et al. 1999), and a fourth sound (short pulses from 98 Hz to 25 Hz, termed D) has also been described (see Appendix, Thompson et al. 1996).

Northeastern Pacific blue whale calls were detected at La Perouse Bank, but not at Union Seamount. The typical blue whale A and B calls were detected at La Perouse Bank on 10 and 14 September 2007 (Figure 17) and atypical blue whale calls were detected on 4 and 14 September (Figure 19). The atypical calls closely resemble the B call third harmonic, but have very little energy below 50 Hz and no energy below 30 Hz.

In addition, there is no evidence of any A calls in these signals. These atypical calls also resemble the so-called "52-Hz whale" calls, which consist of a repeated series of 3-10 s tones sweeping down over 2 Hz, centered on the dominant frequency of 50-52 Hz, with a 3-30 s interval between calls (see Appendix, Watkins et al. 2004). However, the duration of this call is similar to that of the blue whale B call, and is too long for "52-Hz whale" calls.

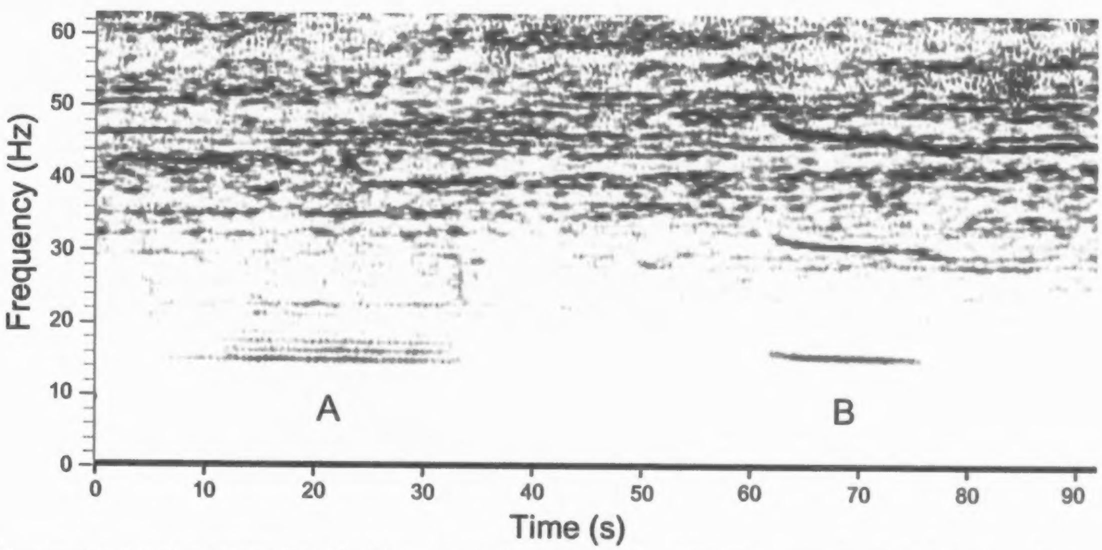

Figure 17. Northeastern Pacific blue whale A and B calls at La Perouse Bank, 10 September 2007. Spectrogram parameters: 1024 pixels image height, 195.4 Hz max frequency, 1024 FFT size, Hanning window.

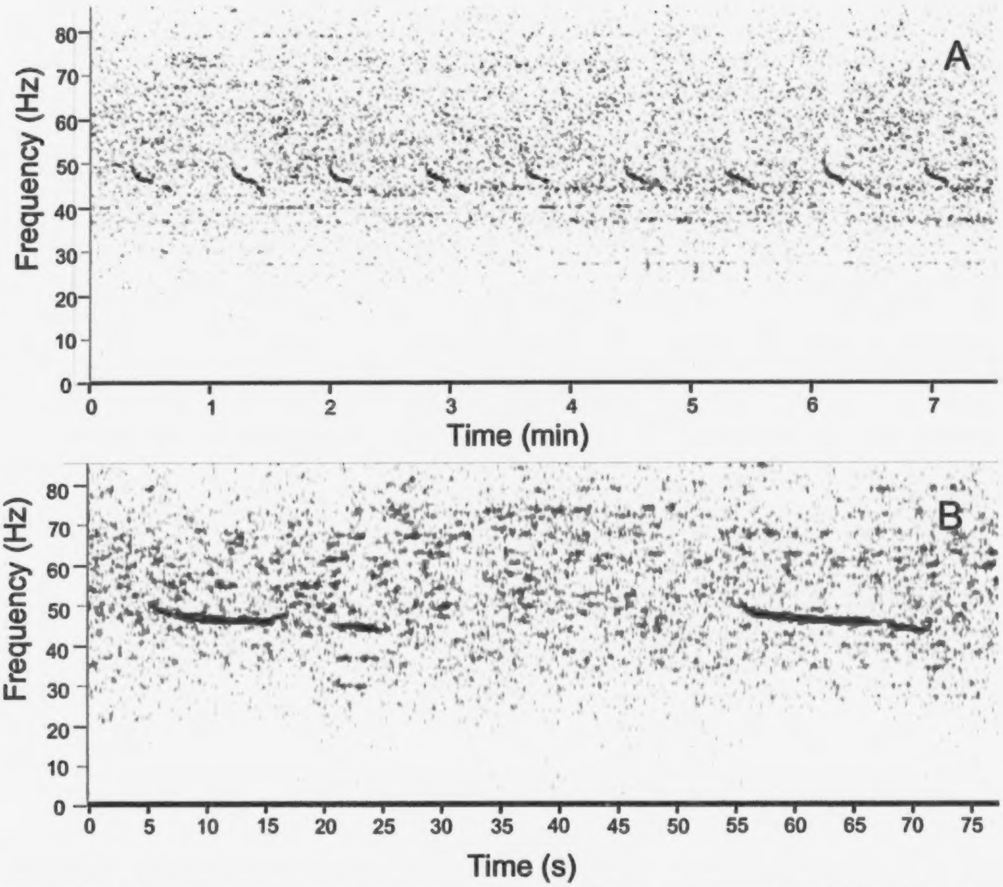

Figure 18. Atypical blue whale calls at La Perouse Bank, 4 September 2007. A) A section of a sequence of calls; Spectrogram parameters: 512 pixels image height, 162.83 Hz max frequency, 1024 FFT size, Hanning window B) horizontal zoom of the first two calls in the sequence; Spectrogram parameters: 512 pixels image height, 162.83 Hz max frequency, 512 FFT size, Hanning window.

Blue whales were detected on 4, 10 and 14 September 2007 at La Perouse Bank (Table 2, Figure 4). This is consistent with findings that blue whales in the northeastern Pacific are vocal from summer to early winter (Watkins et al. 2000, Stafford et al. 2001, Stafford 2003, Burtenshaw 2004) and, more specifically, that blue whales are vocal off the west coast of Vancouver Island from August to March (Burtenshaw et al. 2004). Burtenshaw et al. (2004) show that the northward migration of calling blue whales coincides with the northward bloom of primary production, and suggest that calling blue whales offshore of Vancouver Island (an area with high primary productivity) in the fall indicates an important foraging ground.

3.6 NORTH PACIFIC RIGHT WHALE

North Pacific right whales most commonly produce a signal known as the 'up' call (McDonald and Moore 2002). They also produce sounds termed down-up, down,

constant (tonal and wavering), and unclassified (see Appendix, McDonald and Moore 2002). On average, the 'up' call sweeps from about 90 Hz up to 150 Hz over 0.7 s, and is typically produced in series of 10-15 calls followed by periods of silence (McDonald and Moore 2002).

No right whale vocalizations were detected during the study periods at Union Seamount and La Perouse Bank.

3.7 UNIDENTIFIED SOUNDS

A sound termed "unknown 1" could not be attributed to any species, but it is probably produced by a baleen whale. Unknown 1 (Figure 19) is a broadband, slightly downswept, loud call, recorded at Union Seamount but not at La Perouse Bank.

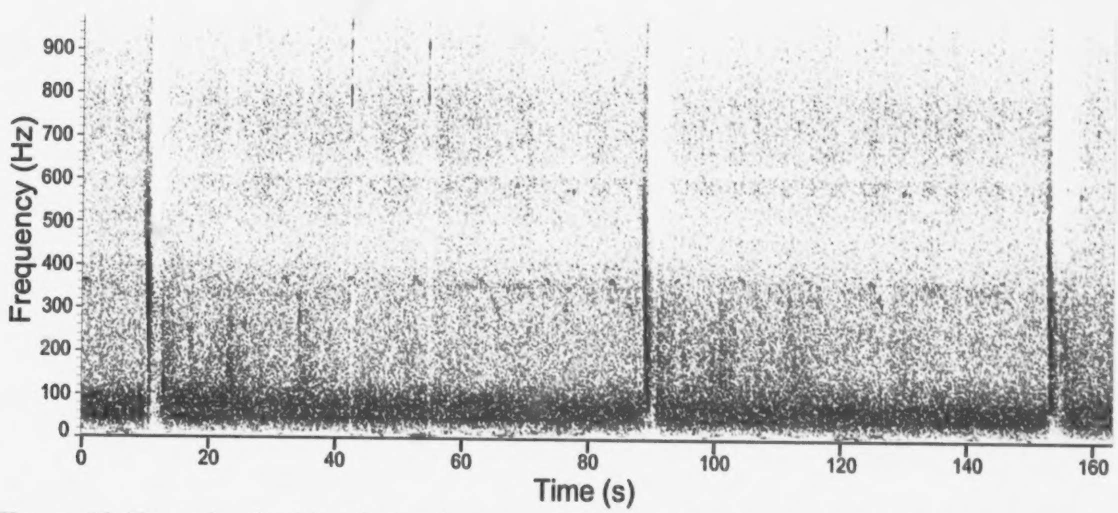

Figure 19. Example of unidentified call termed "unknown 1" at Union Seamount. Spectrogram parameters: 512 pixels image height, 977 Hz max frequency, 1024 FFT size, Hanning window.

Another sound of unknown origin, termed "unknown 2", was recorded throughout the study period at Union Seamount (Figure 20). Superficially, this sound resembles blue whale calls due to its low frequency but the elements of the sounds are too short and there are too many components below 40 Hz to be blue whale calls (Kate Stafford, Ocean Acoustics Department, Applied Physics Laboratory, University of Washington,□1013 NE 40th Street,□Seattle WA 98105-669, pers. comm.). The only other whale that vocalizes at frequencies below 40 Hz is the fin whale, and the low frequency sounds of "unknown 2" are not characteristic of fin whales in any way. Because a baleen whale is not thought to be producing these sounds, it has been suggested that the sounds could be produced by a type of fish (Kate Stafford, pers. comm.). It is also possible that there is an anthropogenic source, although the characteristics of the sounds suggest otherwise.

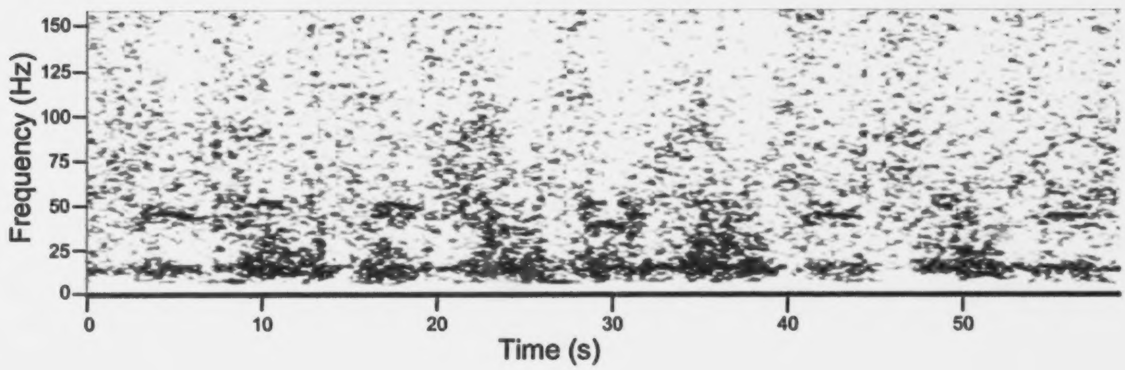

Figure 20. Example of 'unknown 2' sounds at Union Seamount. Spectrogram parameters: 512 pixels image height, 488.5 Hz max frequency, 1024 FFT size, Hanning window.

4.0 CONCLUSIONS AND FUTURE DIRECTIONS

Vocalizations of the humpback whale, fin whale, blue whale, sperm whale, and possibly the sei whale were detected during acoustic instrument deployments at Union Seamount and La Perouse Bank. The number of call detections was higher at La Perouse Bank than at Union Seamount for all species (except for possible sei whale calls, for which proportions were equal). This trend could be due to differences in location, year, and/or time of year of the deployments.

The humpback whale was the species most often detected at both Union Seamount and La Perouse Bank. Humpback whales were also the most frequently observed species during shipboard cetacean surveys in BC waters during 2002-08 (Ford et al. in prep). Humpbacks were sighted in all four seasons, with most sightings occurring in summer and fewest in winter (Ford et al. in prep). At Union Seamount, acoustic detection of humpback whale song was greatest during February and March then decreased sharply in April and ceased by mid May. Social sounds were also virtually absent after mid May. This pattern likely reflects the detection of humpbacks while migrating northward from low latitude winter breeding areas. At La Perouse Bank, humpback whale singing was detected in spring, ceasing at the start of summer and then starting again in late summer. Social sounds were detected throughout the study period, showing that whales were present (though not singing) during the entire period. This continuous presence of humpbacks is likely due to the importance of this area as feeding habitat during summer and fall, and the increasing number of humpback detections (both song and social sounds) in August and September may indicate increasing whale abundance or increasing vocal activity as the breeding season nears, or both.

Fin whales were the second most often detected species at Union Seamount, and the third most often detected at La Perouse Bank. The proportion of detections was slightly higher at La Perouse Bank than at Union Seamount. Similarly, fin whales

were the third most encountered species during the visual cetacean surveys (Ford et al. in prep). Although fin whales were observed throughout the year, they were encountered most often in the summer (Ford et al. in prep). This coincides with the increase in acoustic detections in the summer at La Perouse Bank. Although acoustic monitoring did not encompass a full year, fin whales were detected acoustically at both recording sites in all months with effort. The stereotyped 20 Hz pulse (breeding call) was detected in the winter and early spring at Union Seamount, suggesting that fin whale breeding may be occurring in this area.

Sperm whales were the third most detected species at Union Seamount, and the second most detected at La Perouse Bank. The proportion of detections was significantly higher at La Perouse Bank than at Union Seamount. Sperm whales in BC waters are closely associated with the continental shelf break (Gregr and Trites 2001, Ford et al. in prep), and the La Perouse instrument was situated close to the shelf break. Sperm whale clicks were first detected in the spring at Union Seamount, and clicking continued through the spring and summer at both sites. This may reflect the northward migration of male sperm whales in the summer (Angliss and Lodge 2003, Gregr and Trites 2001).

A few calls that may have been produced by sei whales were detected at both Union Seamount and La Perouse Bank, and the proportion of detections are the same for the two sites. No sei whales were seen during shipboard surveys in 2002-08 (Ford et al. in prep). The lack of visual sightings and minimal number of call detections (if the calls were actually produced by sei whales) both support a conclusion that this species is rare in BC waters (COSEWIC 2003).

Blue whales were acoustically detected on three days in September 2007 at La Perouse Bank and not at all at Union Seamount. Although uncommon, blue whales have been sighted during vessel surveys in recent years, particularly during late summer (Calambokidis et al. 2009, Ford et al. in prep). These visual and acoustic detections are consistent with recent findings that blue whales are present and feed in BC waters during summer. Three blue whales photographically identified in BC waters have also been photographed off California, indicating that the blue whales found in BC waters belong to the same population that feeds off California (Calambokidis et al. 2009). Blue whale calls recorded at La Perouse Bank were of the northeastern Pacific call type, which is also produced by blue whales off California (Burtenshaw 2004).

The acoustic instrument deployments described in this report represent the first step in passive acoustic monitoring of large whales off the coast of British Columbia. Continuation of this work will focus on deploying recording instruments across all seasons and in multiple years, and deploying instruments in a greater variety of locations. Data from this additional effort will help to better describe the seasonal trends and differences between sites that were apparent in this study. More recording effort will also increase the probability of detecting species that were not recorded during these two initial deployments, such as the North Pacific right whale. In time, data acquired from a network of acoustic monitoring instruments should provide a valuable

supplement to visual shipboard surveys to better document the seasonal occurrence and habitat use patterns of cetaceans off the Canadian west coast.

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APPENDIX

This appendix provides examples spectrograms taken from the published literature, of characteristic vocalizations produced by the large whale species discussed in this report.

HUMPBACK WHALE

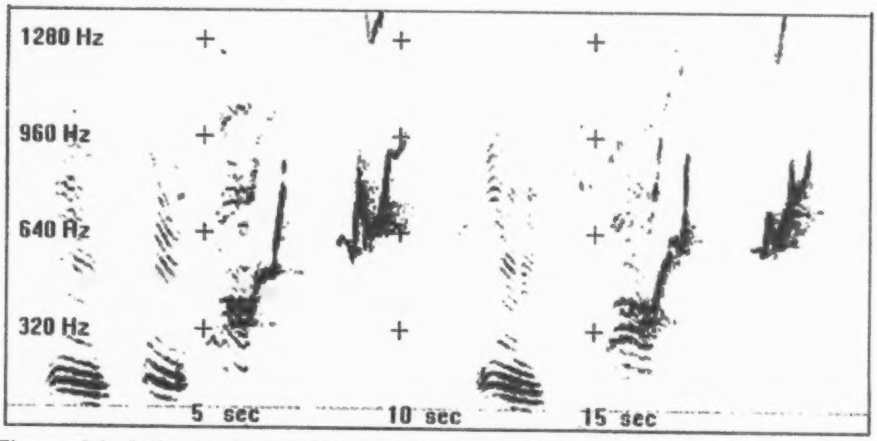

Figure A1. A theme from a humpback whale song; spectrogram parameters: 2048 pt FFT, 5.4 Hz filter b-w, 40 ms time res. (from Norris et al. 2000).

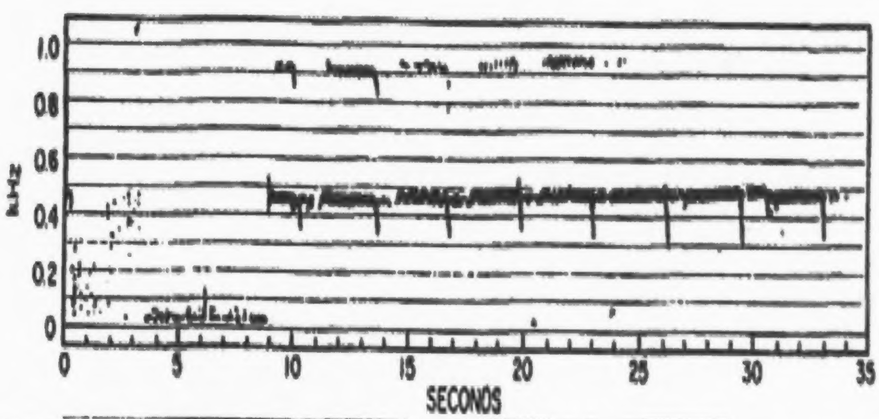

Figure A2. An example of humpback whale social (non-song) sounds- feeding calls (from Frankel et al. 1995).

SPERM WHALE

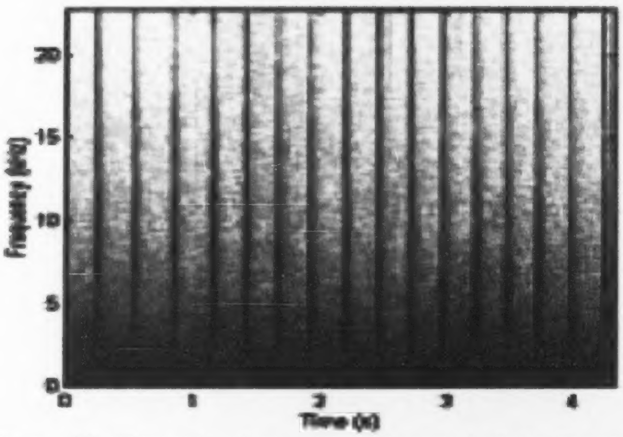

Figure A3. Example of sperm whale usual clicks (from Goold 1999).

FIN WHALE

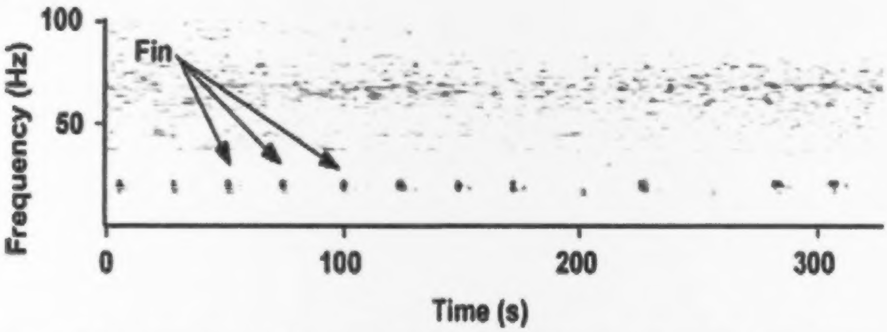

Figure A4. Example of the stereotyped 20 Hz pulses produced by fin whales (from Clark and Altman 2006).

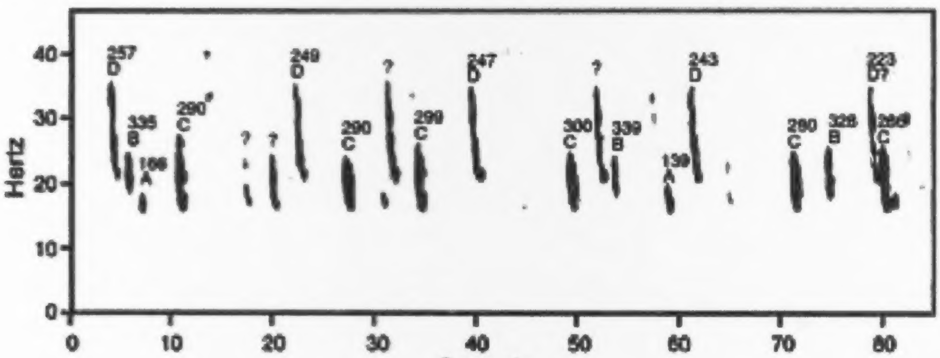

Figure A5. Example of "irregular repetition interval" call type produced by fin whales (from McDonald and Fox 1999).

SEI WHALE

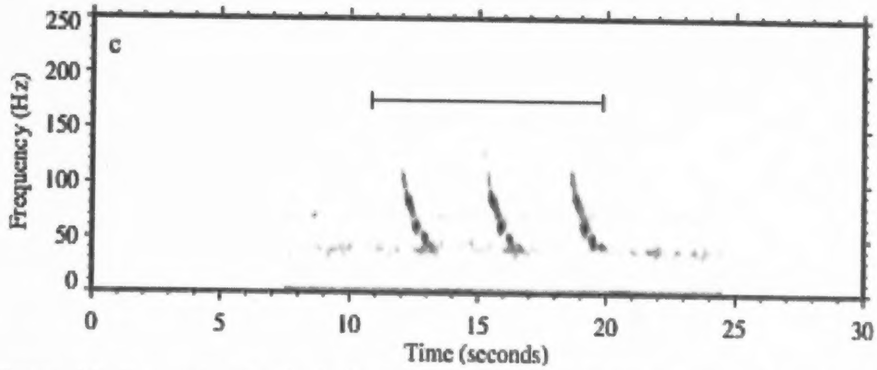

Figure A6. Example of sei whale downsweep calls (from Baumgartner et al. 2008).

NORTHEASTERN PACIFIC BLUE WHALE

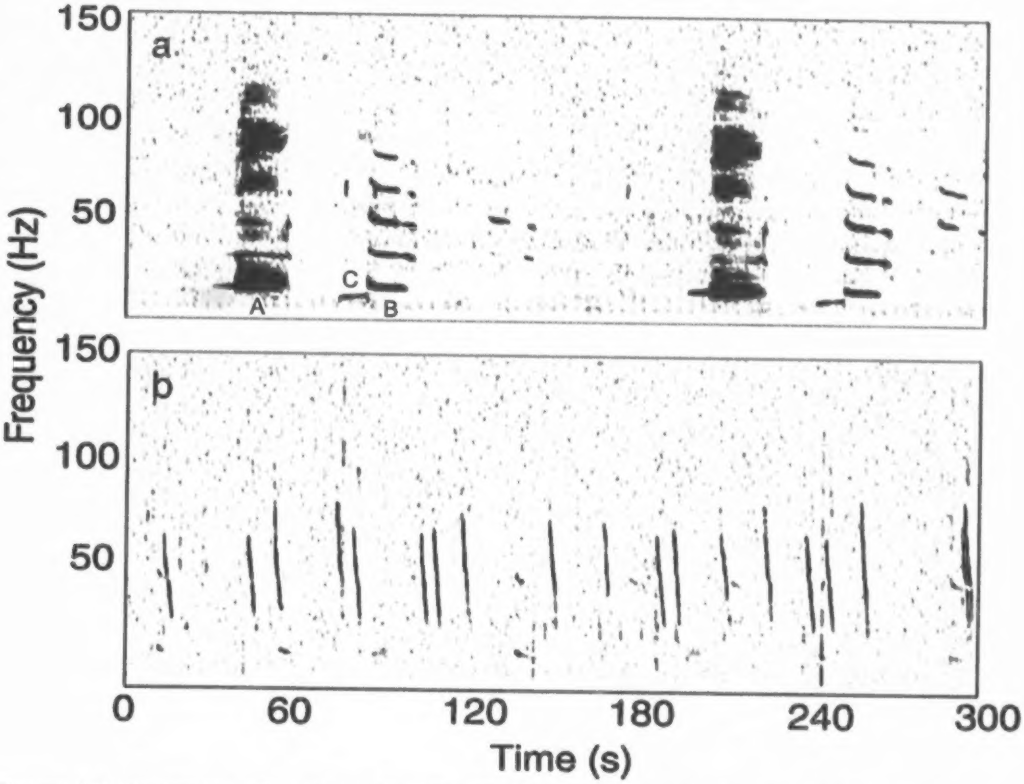

Figure A7. Examples of northeastern Pacific blue whale vocalizations. (a) A, B and C calls; spectrogram parameters: FFT length= 1 s, 90% overlap, Hanning window. (b) variable D calls with faint A and B calls; spectrogram parameters: FFT length=1 s, 25% overlap, Hanning window (from Oleson et al. 2007).

“52-Hz WHALE”

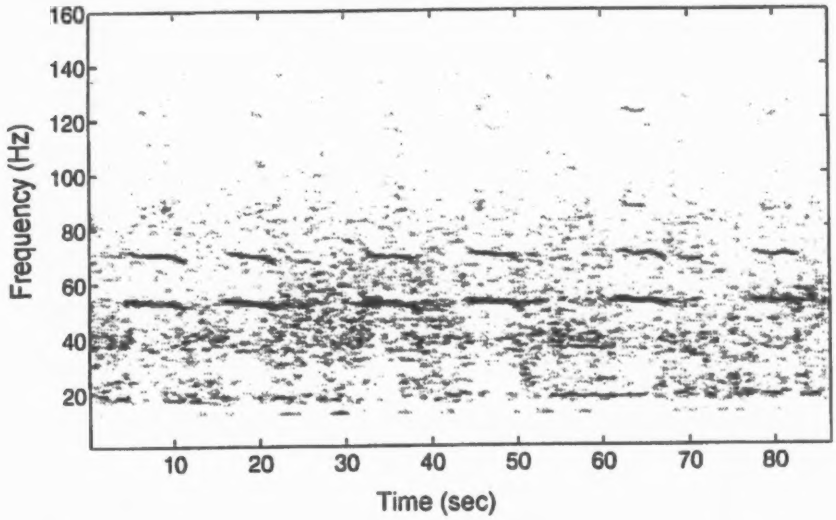

Figure A8. Example of “52-Hz whale” calls (from Watkins et al. 2004).

NORTH PACIFIC RIGHT WHALE

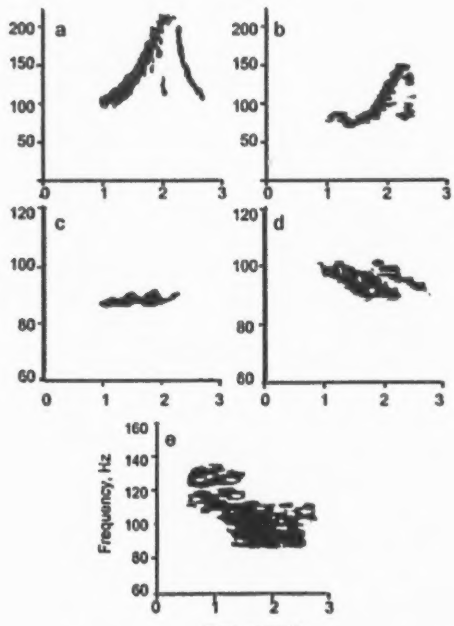

Figure A9. Examples of representative North Pacific right whale call types. (a) up, (b) down-up, (c) constant-tonal, (d) constant-waver, (e) down. Spectrogram parameters: 0.5 second FFT length with 87.5% overlap; note the different frequency scales. Dispersive propagation mode artifacts are visible in all but (c) (from McDonald and Moore 2002).